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TREATMENT AND DISPOSAL OF SEWAGE.

BRIEF DESCRIPTIONS OF METHODS, PROCESSES, AND STRUCTURES USED IN THE TREATMENT AND DISPOSAL OF SEWAGE IN THE UNITED STATES, WITH BIBLIOGRAPHY.

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INTRODUCTION.

This memorandum has been prepared for the purpose of calling attention to methods, structures, and special processes for the treatment and disposal of sewage in the United States.

The descriptions have been made brief and of a very general nature, since it would be impossible to include a complete history of sewage disposal in such a memorandum on the subject. The information is sufficient, however, to give a general idea of the various methods of disposal, and references have been made to literature where complete data may be obtained on the design and operation of any combination of treatment devices discussed in the text.

There is given in the appendix a list of reports covering investigations and recommendations, together with other data relating to sewage disposal for some of the larger cities of the United States. Especial attention is called to the Report of the Metropolitan Sewerage Commission of New York City and to the reports of the Sewerage Commission of the City of Milwaukee. The former contains a very comprehensive review of modern sewage disposal practice, and the latter contains the latest data on the recently developed activated sludge process of treatment.

DILUTION.

The disposal of sewage by dilution consists of its discharge into natural bodies of water, in some cases with and in others without preliminary treatment. In the former instances it constitutes a single and complete method of disposal. In the latter it may be regarded as the final step of a more or less elaborate system of treatment, in which it is employed in conjunction with one or more artificial processes.

Wherever sewage or a sewage effluent is discharged into a natural watercourse, dilution constitutes an integral part of the disposal process.

Dilution has for a long time been the most common means of sewage disposal practiced in the United States. Formerly it was regarded as a temporary and undesirable expedient, to be ultimately abandoned as soon as sewage purification became sufficiently developed. During recent years, however, the economic need for utilizing to the greatest possible extent the self-purification capacity of natural watercourses has been apparent, with the result that the disposal of community wastes by natural dilution has become recognized as a legitimate and desirable process where carried out in such a manner as not to endanger the public health.

Where dilution is successfully applied, it must in general accomplish one or both of the two following results, depending upon the uses to which the receiving body of water is to be subsequently devoted:

1. The limitation of bacterial numbers present in the receiving watercourse to within boundaries safely consistent with the hygienic safety of whatever sources of water supply, bathing beaches, or shellfish areas may be dependent upon such a watercourse.

2. The maintenance of a sufficient reserve supply of dissolved oxygen in the receiving watercourse to insure its freedom from objectionable odors or other conditions, either locally or at more distant points.

In general, the degree of dilution necessary to satisfy the first of these requirements is much higher than that required for the second, although this principle may not necessarily hold if careful local precautions relative to the proper dispersion of sewage are neglected.

The prescription of definite quantitative standards with reference to the dilution of normal sewage has for a long time engaged the attention of sanitary engineers. The first authoritative standard of this sort proposed in the United States was that of Hering, Williams, and Artingstall[1] in 1887, who concluded from a study of data for the design of the Chicago drainage canal that the minimum flow of the canal safely consistent with the avoidance of objectionable conditions should be 3.3 cubic feet per second per thousand of waste-contributing population. This standard was widely accepted for many years.

More recently, however, a further knowledge of the variable part played by self-purification in determining the capacity of water courses for pollution has resulted in a greater degree of caution in attempting to adopt and apply widely any fixed standard of dilu-

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[1] Hering, R., Transactions of Am. Public Health Assoc., Vol. XIII.

tion which must be met at the point of sewage outfall. On the contrary, the present tendency in the United States is in the direction of prescribing standards as to maximum bacterial loads imposable upon water purification plants at the intake, and as to the minimum permissible degree of dissolved oxygen saturation at critical points consistent with the avoidance of nuisance. An example of the former is the so-called International Joint Commission Standard [1] which states that the maximum safe bacterial load imposable upon a modern efficient water purification plant should be such that no more than 50 per cent of 0.1 c. c. portions of the raw water, tested regularly throughout the year, should contain *B. coli.* In terms of the commonly employed *B. coli* index, this is equivalent to a yearly average bacterial load of not exceeding 500 *B. coli* per 100 c. c. An example of the second type of standard noted above is that which was proposed by Black and Phelps [2] as governing the minimum permissible dissolved oxygen content of New York Harbor. This standard, which was given as not less than 70 per cent oxygen saturation, is not concurred in by Fuller, who states [3] that 20 per cent for winter conditions and 30 per cent for summer (each equivalent to about 2.5 parts per million of dissolved oxygen) represent a more practical and generally accepted minimum.

Still more recently the United States Public Health Service has conducted in the Ohio River Basin probably the most intensive scientific study of stream pollution which has ever been carried out. The results obtained from this study, the publication of which is now under way, have thrown considerable new light upon the entire matter of standards of dilution as well as upon the fundamental principles underlying the disposal of community wastes by this method. They have emphasized the great need for caution in applying any fixed standards of dilution to widely varying conditions. At the same time they have shown conclusively that the combined resources of natural dilution and self-purification represent a tremendous economic asset which, in a given case, may be evaluated in definite quantitative terms through properly planned preliminary studies. Such resources should be utilized to the fullest possible extent in connection with any proposed project of sewage treatment involving artificial processes in order that the cost of the latter may be minimized.

A full description of the theory and practice of dilution processes is given by Metcalf and Eddy and by Fuller in the general references (15 and 16) accompanying the present discussion.

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[1] International Joint Commission, Final Report on Pollution of Boundary Waters.
[2] See reference No. 14 in bibliography to present section.
[3] Fuller, G. W., sewage disposal, 1st edition, pp. 217–218.

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3. Chicago Drainage Canal—Efficiency of Disposal by Dilution: Engineering Record, vol. 63, p. 79.
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5. Sewage in Sea Water—Investigation by Adeney, Letts, and Richards: Engineering Record, vol. 65, p. 12.
6. Dilution and Sewage Treatment—Testimony of Sanitary Experts on Pollution of Great Lakes Boundary Waters before International Joint Commission; Engineering Record, vol. 70, pp. 128 and 174.
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GRIT CHAMBERS.

In combined sewerage systems, considerable amounts of coarse mineral matter enter the sewers. Where sewage is pumped or treated, or both, it is generally advisable to remove this matter in order to prevent injury to the pumps and interference with the treatment processes. To accomplish this removal, the sewage is passed through small tanks so designed as to reduce the velocity to a point where deposition of this suspended mineral matter will take place, but not to a point where deposition of the organic matter in suspension will take place. In general this velocity should not average less than 1 foot per second.

As constructed, grit chambers precede the screens and are in two or more units in order to facilitate cleaning.

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SCREENING.

Screens have been used in connection with sewage disposal since the installation of the first sewage-pumping plants. Originally they were installed to remove coarse material that would tend to clog and break the pumps, but later they came into use for removing the finer particles from sewage that caused trouble in operating treatment plants, or produced nuisance in bodies of water receiving raw sewage. Those used for protecting sewage pumps have been classed as coarse screens, while those installed to remove finer particles have been referred to as fine screens. There is no general agreement as to what constitutes a coarse or a fine screen except as to the purpose for which they are installed.

There are many designs for coarse screens, but the type most generally used consists of vertical bars spaced 1 inch to 4 inches apart, and set in frames inclined 30° to 45° from the vertical. They may be cleaned in place by hand-raking or they may be lifted mechanically and raked. There are no particular difficulties involved in designing screens of this type, and for special references to installations in this country attention is called to the bibliography at the end of this chapter.

Fine screens first came into prominence in Europe, but recently they have been given considerable attention in this country. The first large installation was the revolving cylindrical screen at Reading, Pa. It was operated to remove the coarse suspended matter from raw sewage so as to prevent the heavy scum formation in the septic tanks, and the clogging of the sprinkling nozzles. At Baltimore, Md., a large cylindrical screen was operated to remove the floating particles from the effluent of the septic tanks that had caused clogging of the nozzles of the filters. The original screen at Reading was covered with 40-mesh monel metal wire cloth and protected by a $\frac{5}{8}$-inch mesh screen of No. 12 copper wire. In later installations of this type of screen at other cities by the designer, 30 and 32-mesh wire cloth were recommended. The Baltimore screen was covered with 26-mesh monel metal cloth supported by heavy copper wire cloth. There was only a small amount of material to be removed by the Baltimore screen, and the cost of operation was very low; while at Reading the suspended matter removed from the raw sewage was relatively high and the cost of operation likewise was in proportion. These two screens represent the practice of screening sewage where treatment plants are in operation.

Fine screens have also been considered extensively in connection with the disposal of sewage by dilution. The visible surface pollution of the water-fronts of many of our rivers and harbors has become a nuisance before the diluting capacity of the body of water has been reached. In such cases it has been recommended that the sewage be passed through fine screens in order to remove the material that rises to the surface. The Riensch-Wurl screen has been installed in many places in this country to remove coarse material from sewage preparatory to discharging into water courses. The tests of this screen at Cleveland, Ohio, and Brooklyn, N. Y., are of special interest, and the Report of the Metropolitan Sewerage Commission of New York City throws much light on the whole subject of fine screens. References to the reports mentioned above and all other important installations or tests are given in the bibliography at the close of this chapter.

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SEWAGE TREATMENT TANKS.

In order to remove from sewage finely divided suspended and colloidal matter which readily passes through screens and grit chambers, sedimentation has been widely used. Sedimentation processes are of two general types: plain sedimentation, where mechanical settling is alone attempted, and sedimentation combined with some form of

sludge digestion for reducing the volume of sludge obtained in the settling process in which the bacterial action plays a part.

Plain sedimentation.—Plain sedimentation of sewage may be effected either by allowing the liquid to stand in tanks for a certain period of time or by allowing it to flow slowly and continuously through tanks while the suspended matter settles to the bottom. Owing to practical difficulties of operation of the former method, continuous-flow tanks are preferred. Many studies of sedimentation have been made, the results of which are to be found in the literature on the subject. The period of detention is an important factor in the design and ranges from 30 minutes to 6 hours. Longer periods are generally unnecessary and may even prove detrimental if the effluent is to undergo further treatment.

Plain sedimentation tanks may be either of the horizontal or vertical flow type. Horizontal tanks may have level or inclined bottoms, the latter usually being deepest at the inlet end. Circular, vertical-flow tanks may have conical bottoms for sludge storage, with the inlet above the conical section and the outlet at the top of the tank. In order to operate, the upward velocity of flow in vertical tanks must be less than the downward rate of travel of the settling material. The Dortmund and Watson tanks are examples of the vertical-flow principle.

Chemical precipitation.—In order to hasten and extend the action of plain sedimentation, chemicals of various kinds may be added to the sewage which will coagulate and envelop or combine with the suspended, colloidal, or soluble matter and carry it to the bottom of the tank. The most common chemicals used are lime, alum, ferrous sulphate, ferric sulphate, and alumino-ferric. The degree of precipitation effected depends upon the amount of chemicals used. From 65 to 90 per cent of suspended matter is generally removed by this method, though the cost is at times prohibitive. The effluent is comparatively clear with decreased bacterial content. Large quantities of sludge are formed, which is usually costly to dispose of, and this is one of the principal objections to the method.

Septic tanks.—Various forms of tanks have been devised to liquefy the settled material and make its further disposal less costly and objectionable. The Cameron septic tank was one of the first steps in this direction. It consisted of a tightly covered horizontal flow tank, in which the period of detention was extended to about 24 hours, to allow anaerobic bacteria to liquefy the settled sludge. Considerable quantities of gases are generated, which in escaping tend to nullify in part the sedimentation process. The odor of the effluent is often marked, and it may contain substances that render its further treat-

ment difficult. This form of treatment has been practically abandoned in favor of more satisfactory methods of disposal.

Travis tanks.—Two-story tanks of various design are intended to allow sludge decomposition to proceed separately from the sedimentation process of the raw sewage. The original Travis, or hydrolytic tank, consisted of a horizontal chamber with semicircular bottom divided longitudinally into three compartments by means of two division walls starting at the bottom sides and extending upward and sloping inward at an angle of 45 degrees until nearly meeting, then extending vertically to the top of the tank. Slots at the bottom of the division walls allowed the sludge from the sedimentation compartments at the sides, together with some fresh sewage, to flow into the central division, there to undergo further digestion or decomposition. Still further treatment of the effluent was obtained by passing it upward through coarse stone filters, called hydrolyzing chambers.

Imhoff tanks.—The most satisfactory type of two-story sedimentation and sludge-digestion tank in general use is known as the Emscher, or Imhoff tank, named for its inventor, Dr. Carl Imhoff. This tank is similar in many respects to the Travis tank, except that no sewage is allowed to enter the sludge chamber, and the sedimentation period is shorter.

Imhoff tanks are of two general types: the radial or down-and-up flow, and the longitudinal flow. The former type is circular in plan, while the latter, which is generally used, may be circular, square, or rectangular. The sedimentation chamber forms the upper story and has a sloping bottom with slots through which the settled sludge slides into the digestion chamber underneath. The slots are trapped in such manner as to prevent the passage of gases through the sedimentation chamber.

The detention period of sewage in the Imhoff tank ranges from $2\frac{1}{2}$ to 3 hours and the velocity is approximately 0.6 feet per minute through the sedimentation chamber. The amount of suspended matter removed varies with different sewages, but in general it ranges from 55 to 75 per cent. The sludge chambers are usually designed to hold from six to eight months' accumulation of sludge.

Advantages claimed for the Imhoff tank method of treatment are the production of a fresh, nonseptic effluent and a sludge low in amount, inoffensive, and readily dried. Many large-sized installations of Imhoff tanks have been made, the literature of which is quite complete.

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SLUDGE.

The disposal of the sludge that accumulates in the various forms of tanks that have been developed for removing suspended matter from sewage has been one of the most difficult problems that sanitary engineers have been called upon to solve in connection with the purification of sewage. Three methods of disposal have been used: (1) hauling the sludge out to sea and dumping it; (2) air-drying on open shallow filter beds; (3) dewatering in filter presses.

Disposal at sea.—The method of disposal at sea, obviously, is applicable only to cities located on the seashore. The sludge is pumped from the settling tanks into tank steamers and hauled out to sea and dumped. It is practical and probably the cheapest way to dispose of sludge. There are no cities in the United States located on the seaboard that have disposal plants which dispose of their fresh sludge in this manner. The city of Providence, R. I., however, hauls the pressed sludge to sea and dumps it.

Air-drying on open beds.—Air-drying on open beds is the method generally practiced in this country. The beds are ordinarily composed of one foot of sand, about four inches of coarse gravel, and tile underdrainage. Earth embankments are thrown up around the sand and the sludge is run on to a depth of 8 to 10 inches. If more than 8 to 10 inches of sludge is applied to the beds it will dry at the surface and the sand will clog at the top, thus leaving a layer of wet sludge in between. In shallow layers the surface cracks will extend through to the sand, and the sludge will dry to a spadable condition in 15 to 20 days during the summer time. After drying, the sludge is hauled away either in small cars or on wagons to dumps. In a few places it is sold as fertilizer to farmers at a nominal sum. For smaller cities this method is practical and economical; but for the large centers of population it may be expensive, and may also give rise to nuisance from the odors arising from the exposure of such a large area of fresh sludge. No other method, however, has been developed to take the place of air-drying that is economically feasible.

Sludge pressing.—The pressing method of removing water from sludge so that it can be hauled away and be disposed of has been in use in this country and abroad for many years. At Worcester, Mass., filter presses were installed in 1898, and at Providence, R. I., about 1901, but the principle has never been generally accepted as the most economical method. Within the last few years, however, considerable interest has been taken in sludge pressing, owing to new developments in treating sewage by the activated sludge method. By this system a large volume of sludge of a high water content (98 per cent) is obtained that has high fertilizing ingredients. In order

for this method to become practical it is necessary to develop some scheme for dewatering the sludge that is more practical than air-drying and less expensive than filter pressing with the older types of presses. This subject has been investigated by several municipalities during the last few years, and progress is reported especially at Milwaukee, Wis. References to reports on experiments made there are given on pages 122–123, and references are given at the end of this chapter to other reports that have been made not only on filter pressing but on other methods employed to dewater and dispose of sludge.

Screenings from coarse and fine screens may be considered as sludge as regards the methods of dewatering. The coarse material can be easily pressed in most any form of machine with success. At many plants presses that are ordinarily used for pressing cider out of apples have been found to work satisfactorily. Centrifugal machines have been used at Reading, Pa., with good results. The dried screenings are burned under the boilers of the pumping stations. The suspended matter removed by fine screens is not as readily pressed as that from the coarse screens; but with this material, presses have given excellent results, and centrifugal machines have also been found satisfactory.

The second and third methods referred to in the preceding paragraphs are employed primarily for drying the sludge. This is, however, the most difficult and expensive part of the disposal, as the actual hauling away of the partially dried cake is not a difficult matter. To offset the cost of drying many attempts have been made to obtain grease and fertilizer from the sludge. Until the development of the activated sludge process little headway was made; but recently the tests made at Milwaukee and at the Stock Yards at Chicago indicate that sludge may be disposed of as a commercial product and the entire cost of drying repaid by the sale of the sludge.

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SEWAGE FILTERS.

There are three general types of filters which are at present employed in the United States in connection with sewage treatment. These are as follows:

1. Contact filters.
2. Trickling or sprinkling filters.
3. Intermittent sand filters.

The main function of all three types of filters is primarily the stabilizing of the organic constituents of sewage oxidation, though intermittent sand filters in addition remove very high percentages of bacteria. Each type of filter will be discussed briefly.

Contact filters.—The contact type of filter, which is described fully by Metcalf and Eddy[1] and by Fuller,[2] consists of a tight tank filled with broken stone and provided with regulating devices for

[1] Metcalf and Eddy, American Sewerage Practice, vol. III, Disposal of Sewage, pp. 223–227; also chapter XLV.
[2] Fuller, G. W., Sewage Disposal, chapter XX.

controlling both inflow and outflow. The ordinary cycle of operation of these filters consists of filling them with sewage, allowing them to stand full for a specified period (termed the "contact period"), emptying them, and allowing them to rest for a relatively long period (termed the "rest period"). Metcalf and Eddy (loc. cit., p. 223) give the following as an average operation schedule:

	Hours
Time of filling	1.0
Time of contact	.75
Time of emptying	.25
Time of resting	6.00
Time of cycle	8.00

The contact bed, which was developed previous to the sprinking filter, represents what was virtually the first logical step in evolving an intensive oxidizing machine from plain tank treatment. For this purpose it has been largely supplanted by the trickling filter, which has proved to be fully as efficient and considerably more economical in its per capita cost. Many filters of this type are in successful operation, however, particularly in the smaller plants. When properly operated they have one advantage over trickling filters when installed in the immediate neighborhood of residences; namely, their greater degree of freedom from odors. Their economic disadvantages, however, combined with their greater difficulty of successful operation, especially in large installations, have in general forced them to give way to the trickling filter.

Trickling filters.—The trickling (sometimes termed "sprinkling" or "percolating") filter represents a further step in the evolution of the contact bed in an effort to produce a more efficient and economical apparatus for oxidizing the putrescible matters of sewage. The filtering medium employed is similar to that which is used in contact filters, but it is so arranged as to facilitate as far as possible the free access of air throughout the interior of the bed. The method of applying sewage to this type of filter consists of spraying it as uniformly as possible over the surface of the bed, allowing it to percolate freely through the medium to a tight underdrain floor, whence the effluent is conveyed to outflow conduits. Ordinarily the sewage is applied intermittently, the regulation of dosage being automatic. An average operation schedule consists of about 5 minutes of application followed by about 10 minutes of rest. The particular schedule adopted depends upon local conditions.

The active purifying element of trickling filters consists of films of bacterial zooglea which form on the surfaces of the broken stone or slag composing the medium. Until these films form and the filter is "ripe," it accomplishes practically no work. The material com-

posing the films, which is virtually activated sludge,[1] removes, by adsorption and absorption, the suspended and dissolved organic substances brought into contact with it. The activities of aerobic bacteria growing within the films then bring about the oxidation of such substances, the basic supply of oxygen for this process being supplied by the air circulating within the bed. The stabilized products of oxidation resulting from this process are gradually returned in solution to the films of percolating sewage and thus carried off in the effluent. This, in brief, is the mechanism of the oxidation process.

The depth of trickling filters at present in use in the United States varies from about 5 feet (as at Columbus, Ohio), to as much as 9 feet (as at Baltimore, Md.). Still deeper filters have been proposed for Indianapolis, Ind., by Mr. Fuller, as described in reference No. 16 of the bibliography of this section. In general, the permissible rate of application of sewage to trickling filters consistent with good results is roughly proportional to their depth. This rate varies from about 2.0 million gallons per acre daily for 5 and 6 foot depth filters to about 2.5 million gallons for those of 9 foot depth.

Trickling filters perform efficiently under a wide range of seasonal conditons, their general activity, however, being somewhat less in winter than in summer. During the cold season the bacterial films accumulate to their maximum thickness. With the advent of spring and an increasing activity of numerous worms and larvæ inhabiting the beds, the films become loosened and slough off, producing the self-cleansing or unloading phenomenon which is characteristic of this type of filter. Periodic unloadings may occur throughout the summer.

Well designed and operated trickling filters ordinarily produce an effluent containing, in the form of nitrites, nitrates, and dissolved oxygen, fully 90 per cent of the total oxygen required to satisfy its residual oxygen demand. Excepting during unloading periods such filters also bring about a considerable degree of clarification and bacterial removal. Since the suspended matter contained in the filter effluent is more or less agglutinated and readily subsides, a comparatively brief period of sedimentation following filtration will bring about a marked improvement in the physical and bacterial characteristics of such an effluent.

The trickling filter is frequently employed in conjunction with preliminary sedimentation and screening processes for the purpose of producing a highly stable effluent. Where a high degree of removal of suspended matter and bacteria is also desired, secondary sedi-

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[1] See discussion entitled "Activated Sludge," page 121.

mentation of the filter effluent, followed in some cases by disinfection, is practiced. In order to minimize the clogging of spray nozzles it is customary to pass the sewage through fine screens before applying it to the filters. This type of filter is at present considered the most practicable and economical means available for oxidizing sewage. A full description of it is given by Metcalf and Eddy in chapter XV, and by Fuller in chapter XXI, of the general references numbered 25 and 24, respectively, of the bibliography accompanying the present section. An outline of the theory underlying this type of filter is given by Metcalf and Eddy on pages 227 to 231 of the former reference.

Intermittent sand filters.—The application of intermittent sand filtration to the treatment of sewage, which was inaugurated at the Lawrence (Mass.) Experiment Station in the late eighties marked practically the first important step in the development of sewage purification in the United States. The subsequent use of this process, however, has largely been confined to the New England States and to other areas, principally along the Atlantic Coast, where natural deposits of sand are abundant.

The intermittent sand filter is extremely simple in construction, consisting of a layer of natural sand about 4 feet deep graded to a level surface and underdrained with either a deposit of natural sand or a tile underdrain system. It is provided with apparatus, usually radiating surface troughs, for distributing the sewage evenly over the filter, and, in some cases, with automatic devices for controlling the intermittency of application of the sewage.

The action of an intermittent sand filter consists of both mechanical straining and biochemical oxidation. The former mechanically removes a high proportion of the suspended matter and bacteria contained in the applied sewage, while the latter, by biochemical processes very similar to those taking place in the trickling filter, brings about an oxidation of dissolved organic matter into stable products. A large proportion of the mechanical straining action takes place in the upper layer of the filter, this being aided materially by the "ripening" of the sand grains and the deposition of a gelatinous zooglea mat at the surface. After a certain period of operation of the bed, it becomes clogged and must be cleaned. This is usually accomplished by removal of the top layers of sand and the accumulated mat. While, as noted above, the oxidizing action of this type of filter is similar to that of the trickling filter, the degree of nitrification which it accomplishes is in general greater.

The operation of intermittent filters is simple, consisting of the intermittent application of sewage from one to three times daily, fol-

lowed by draining and a period of rest sufficient in length to permit the circulation of air throughout the bed. At the beginning of the operation of a new or a recently cleaned bed the distribution of sewage over it will not be very uniform, since the greater proportion of it will seep through the sand near the distributors. As this area becomes partially clogged, more and more sewage will seek the distant points and the uniformity of distribution will be increased. The permissible rate of filtration consistent with good results varies with the character of sewage applied, but on the average it ranges from 10,000 to about 50,000 gallons per acre daily. Filters of this type will successfully treat either raw or settled sewage, though they will require more frequent cleaning in the former case.

From the standpoint of the character of effluent produced, intermittent sand filters are by far the most efficient of the three types which have been considered. When they are performing at their best they produce an effluent which is clear, practically odorless, almost entirely free from suspended matter, and very stable. They also remove a very high percentage of bacteria from the applied sewage. Since, however, a minimum of (roughly) forty times as much area of this type of filter as of trickling filters is required to treat similar amounts of sewage, the relative economy of the intermittent sand filter is very low as compared with the latter type, excepting where land is cheap and large deposits of suitable sand are available at the immediate site of the works. For this reason its use has been confined to comparatively small local areas in the United States.

Full descriptions of this type of filter are given by Metcalf and Eddy and by Fuller in general references numbered 25 (pp. 231–236 and Ch. XVI) and 24 (Ch. XIX), respectively, in the bibliography of the present section.

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DISINFECTION.

Disinfection in the treatment of sewage removes from the sewage the disease-producing organisms which may be present. For this

reason it is generally used in connection with other methods of treatment and as the final process before discharge of the sewage into the receiving body of water.

While proper disinfection of sewage will remove the greater part of the putrefying organisms there are generally a sufficient number of such organisms present in the receiving body of water to again start putrefying action in the organic matter; hence nuisance is not abated by the use of disinfection alone.

As a rule disinfection of sewage and sewage effluents has been adopted only where protection of water supplies, of shellfish beds, and bathing beaches during bathing season has been required.

As at present practiced disinfection consists in dosing or treating the sewage or sewage effluent with calcium hypochlorite or liquid chlorine. At the present time the liquid chlorine is rapidly replacing the hypochlorite.

In operation the hypochlorite or chlorine in solution, or the chlorine as a dry gas, is added to the sewage or sewage effluent, after which a short period of detention is allowed, in order that proper absorption of the chemical may take place.

At present the tendency appears to be more toward the purification and disinfection of water supplies than toward the disinfection of sewage and sewage effluents in order to protect the water supplies.

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4. Sewage Disposal Problem of New Haven.—Report of Commission, pp. 40, 66–70, 1918.

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Sewage Disposal. George W. Fuller. Pp. 726–731.
American Sewerage Practice, Vol. III, Sewage Disposal, pp. 737–782.

BROAD IRRIGATION.

The disposal of sewage upon the land dates back to the development of sewerage itself. The development of broad irrigation began in England in 1858, following the report of the Sewage of Towns Commission, and for a number of years was used extensively in Europe and to some extent in the United States. The method, as its name implies, is the irrigating of cultivated land with sewage.

For the purpose of operation of this method of disposal large areas of light sandy soil are required. On account of the inability

to properly handle the sewage upon areas of more dense or heavier soils, this method has been largely replaced by more modern methods, except in arid regions and in regions where large areas of otherwise waste sandy soil exist.

In general the area necessary will vary according to the character of soil; the rates range from 3,000 to 10,000 gallons per acre per day.

In so far as American practice is concerned, this method of disposal is but little practiced and is on the decline.

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ACTIVATED SLUDGE.

During the past five years a new method of sewage disposal has been developed which gives great promise of success—the activated sludge method. This method is beyond the experimental stage at present, excepting the methods of handling and disposing of the sludge. At the present time a few plants have been constructed and several are contemplated.

Theory.—Aeration of sewage with finely divided air causes the suspended and colloidal matter in the sewage to gather, forming a flocculent precipitate in which large numbers of bacteria are accumulated. Conditions in the flocculus thus formed and in the presence of air appear to be very favorable for the multiplication of nitrifying organisms. Sludge thus formed and "seeded" with nitrifying bacteria is known as "Activated Sludge." When such activated sludge is added to fresh sewage and the whole aerated for short periods with finely divided air, a nitrification of the sewage, a high removal of bacteria, and a quick-settling sludge formation takes place. The effluent from plants of this type shows a bacterial reduction of over 90 per cent, and is clear and stable.

The sludge formed contains approximately 98 per cent water, and is therefore voluminous. The proper handling and disposing of the large amount of putrescible sludge has constituted one of the objections to this type of plant.

Outline of plant.—A plant of the activated sludge type consists in general of continuous flow sewage aerating tanks, settling tanks, sludge aerating tanks, sludge disposal apparatus, and the mechanical equipment for pumping, compressing air, etc.

Process.—The process is in general as follows: Approximately 20 to 25 per cent of well-activated sludge is added to the raw sewage as it enters the aerating tank. As the sewage with its added activated

sludge passes through the tank it is constantly aerated by air fed through diffusers in the tank bottom. From the aerating tank the mixed sewage and sludge pass to the settling tank in which the sludge settles rapidly, the supernatant matter passing off through the effluent outlet.

From the settling tank a portion of the sludge is drawn off to the sludge aerating tanks and further aerated to prepare it for addition to the incoming fresh sewage. The sludge accumulations in the settling tank are drawn off for dewatering and disposition.

Advantages and disadvantages.—The advantages of this type of treatment are the small area required and the reduced cost of construction.

The disadvantage at present is the question of sludge disposal.

General.—Following rather exhaustive experiments, the city of Milwaukee, Wis., has adopted the activated sludge process of sewage treatment, and has constructed one large unit which is being operated as an experimental unit.

Description of the experiments, the construction, etc., will be found in the second, third, fourth, and fifth annual reports of the Sewerage Commission of the City of Milwaukee, Wis., and in articles published in various engineering publications listed hereinafter.

A plant of the activated type has been recommended for the treatment of the sewage and packing-house wastes of Packingtown, the stockyard, and packing-house district of Chicago.

Several small plants have been constructed, the largest of which is at Houston, Tex. Reference to these plants and to experiments will be found in the bibliography.

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MILES ACID PROCESS.

The Miles acid method of sewage treatment, a patented process, while not yet used at any full-sized plant, seems from various experimental plants to possess considerable merit. The patent claims that the process "(1) Consists in introducing an inorganic acid as the sole effective agent," and "(3) Consists in introducing sulphurous acid into the sewage." Mr. R. S. Weston, one of the experimenters with this method of sewage treatment, explains the method as follows: "The Miles process attempts, by the addition of an acid, to precipitate the bulk of the solids from sewage in the form of a sludge which can be dried and degreased, thereby producing a readily salable and greaseless fertilizer, as well as recovering valuable grease. Either sulphuric or sulphurous acid may be used, and the process contemplates the manufacture of the acid at the disposal works."

Acid is usually added in the form of sulphur dioxide, generated by roasting pyrites, to a part of the sewage by means of an absorption tower and this overtreated part mixed with the entire sewage flow. An acidity of 50 parts per million as calcium carbonate has been found to be sufficient. After acidification the sewage contains bisulphites and some free sulphurous acid, also lime and magnesium soaps, which are attacked by the acid, liberating the free fatty acids. While passing through the sedimentation tanks part of the bisulphites and sulphurous acid are oxidized to bisulphates and sulphuric acid. A sedimentation period of four hours is allowed to the acidified sewage, after which the effluent is drawn off and the sludge dried and degreased by means of ether.

Claims for the process are an effluent almost sterile, stable and clear, and a sludge from which by-products such as grease and fertilizer will eliminate the costs of treatment. Experimental plants have been operated at Boston, Mass., by R. S. Weston, and at New Haven, Conn., by C.-E. A. Winslow, the results of which have been published. Some difficulty seems to have been encountered in se-

curing a salable grease, though the sludge was at all times stable and a high percentage removal of bacteria was effected in the effluent. The effluent seems to have a serious deoxygenating effect on the diluting water into which it is discharged, which may necessitate aeration of the effluent before discharge. Owing to the acid nature of the effluent considerable destructive effects on aquatic life existing in the diluting water may also take place.

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ELECTROLYTIC PROCESS.

The electrolytic process of sewage treatment consists of passing sewage through an electrolytic cell having iron plates, the sewage being untreated or treated with lime before entering the cell.

The action of the cell is to hasten precipitation of the solids in the sewage and to disinfect the sewage through the formation of hypochlorite.

The electrolytic method of treatment may be used simply as a disinfection process, in which case it follows other more or less complete treatment processes. Where the lime electrolytic method is used, the cell is preceded by fine screens and followed by sedimentation tanks and sludge handling apparatus.

Prior to 1914 such experiments as were made and such plants as were installed depended upon the electrolytic action alone, no chemicals being added to the sewage. A brief history of the electrolytic treatment is covered in "Sewage Disposal," by George W. Fuller, pages 550 to 576.

As far as known, but two plants of any size have been installed using the electrolytic type of treatment alone; one is at Santa Monica, Calif., and the other at Oklahoma City, Okla. Neither of these plants can be considered as complete sewage disposal plants. Description of them will be found in *Engineering* and *Contracting*, April 19, 1911, *Municipal Journal* and *Engineer*, February 8, 1912, and the *Engineering News*, March 21, 1912. The last-mentioned journal also has a comprehensive review of the whole subject of electrolytic treatment up to the date given.

In order that nuisance may be avoided in the body of water into which the sewage is ultimately discharged the plain electrolytic method of treatment will require a plant comprising grit chambers, fine screens or preliminary tanks, electrolytic cells, and possibly sludge-disposal apparatus. A small plant having Imhoff tanks preceding the electrolytic apparatus is in operation at Durant, Okla. The description, with results of tests made at this plant, will be found in the *Engineering News*, volume 76, page 547.

In the past few years experiments have been carried on with the lime-electrolytic method of sewage treatment. This process, patented by C. P. Landreth, of Philadelphia, Pa., consists of first adding lime to the sewage, after which it is passed through the electrolytic cell.

So far as is known no municipal plants or plants of any size are in operation or contemplated.

In 1914 an experimental and demonstration plant was installed at Elmhurst, Borough of Queens, Brooklyn, N. Y.; in 1916 one at Decatur, Ill.; and in 1918 one at Easton, Pa.

Descriptions and comments upon the first-named plant will be found in the *Engineering Record*, volume 70, pages 285, 299, 315, 429, and 430. Other articles covering the operation of this plant will be found in *Metallurgical* and *Chemical Engineering*, volume 13, Nos. 12 and 13, October 15 and November 1, 1915; in the *Canadian Engineer*, November 5, 1914; and the *Municipal Journal*, November 5, 1914.

Attention is also called to a report on sewage disposal at Lexington, Ky., by Surg. W. H. Frost and Sanitary Engineer R. E. Tarbett, of the United States Public Health Service, dated January 13, 1916, and to a report by Prof. E. B. Phelps, of the Hygienic Laboratory, United States Public Health Service, upon the electrolytic method. Both of these reports are on file at the Bureau of the Public Health Service. References to the Decatur, Ill., plant will be found in the *Municipal Engineer*, February 18, 1918, and the *Engineering News-Record*, volume 74, November 11, 1916, pages 575 and 596. The last-named reference is an abstract of a report by Edward Bartow,

director of the Illinois State Water Survey, on comparative tests of the lime-electrolytic process and of lime treatment alone. According to this report, the results would indicate that the lime-electrolytic treatment is little better than lime treatment alone. Unfortunately the tests were of rather short duration, as the company controlling the patents, objecting to comparative tests, dismantled the plant.

An abstract of the report on tests made at the Easton, Pa., plant by the Engineering Division of the Pennsylvania State Department of Health and by a committee of the Franklin Institute will be found in the *Engineering News-Record*, volume 83, September 18, 1919, pages 569–573. A complete report of the committee from the Franklin Institute is published in the *Journal of the Franklin Institute* for August, 1919.

The plant layout, which was more or less similar in each of the three installations, was as follows:

1. Coarse bar screens followed by fine screens.
2. Pumping equipment for lifting sewage and furnishing a sufficient operating head.
3. Lime-mixing tanks.
4. Mixing chambers or channels for mixing the lime solution with the sewage.
5. Electrolytic cells.
6. Final sedimentation tank, with a sedimentation period of 4½ hours.
7. Sludge-disposal apparatus.

The effluent obtained from the Landreth "Lime-Electrolytic" or "Direct-Oxidation" method of treatment, judging by the results published, is very satisfactory. The operating costs are, however, far in excess of the cost necessary to obtain effluents of comparable quality by means of methods now in general use.

The sludge formed appears to be comparable with the sludge from the chemical precipitation method, both as to quantity and characteristics. The recommendations of the patentee are, apparently, that this sludge be handled by filter pressing, as is the sludge from the chemical precipitation plants where lime is used.

Present Status.

Plain electrolytic treatment.

Judging from such tests as have been made of the electrolytic treatment for the sterilization of sewage, operation is erratic and results show great variations.

The costs of operation are greater and results less reliable than is the case when calcium hypochlorite or liquid chlorine is used for disinfection.

Lime-electrolytic or direct-oxidation method.

The process is in the experimental stage.

The cost of operation is excessive.

The practicability of the process has not as yet been recognized by the engineering profession.

Conclusions.

In its present status any installation of the lime-electrolytic or direct-oxidation method on a large scale should be preceded by the installation of a test unit. This unit should be operated for a period sufficiently long to insure any inherent mechanical defects in the apparatus and to demonstrate its ability to maintain a uniform efficiency.

In view of the fact that equally good results are claimed with the use of lime alone, comparative tests should be carried on simultaneously in order to prove or disprove this contention.

All tests should be under the direction of disinterested parties, but in cooperation with the patentee or his representative.

References.

IN CURRENT ENGINEERING LITERATURE.

1. Description of the Electrolytic Sewage Plants at Santa Monica, Calif., and Oklahoma City, Okla.: Engineering and Contracting, April 19, 1911.
2. Same as (1) above: Municipal Journal and Engineer, February 8, 1912.
3. Comprehensive Review of the Electrolytic Treatment prior to 1912; Engineering News, March 12, 1912.
4. Electrolytic Treatment of Sewage at Oklahoma City: Engineering Record, vol. 66, p. 55.
5. Description and Abstract of Tests of an Imhoff Tank-Electrolytic Plant at Durant, Okla.: Engineering News, September 21, 1916, p. 547.
6. Second Annual Report of the Sewerage Commission of City of Milwaukee, 1915, pp. 69 and 106–108.
7. Report on Electrolytic Treatment (Elmhurst Plant). P. M. Travis. Comments by C. P. Landreth and E. B. Phelps: Engineering Record, vol. 70, pp. 285, 299, 315, 429, 430.
8. Electrolytic treatment of sewage—Information from a report by Elmer W. Futh upon the operation and results obtained at Elmhurst (N. Y.) disposal plant by the method patented by C. P. Landreth. Canadian Engineer, November 5, 1914.
9. Electrolytic Sewage Treatment Tests in a Plant Treating 750,000 gallons per day: Municipal Journal, November 5, 1914.
10. Description of the Lime-Electrolytic Method of Sewage Disposal: Metallurgical and Chemical Engineering, vol. 13, October 15 and November 1, 1915.
11. Treatment of Sewage with Electricity and Lime: Municipal Engineer, December, 1915.
12. Tests on the Decatur Plant. Edward Bartow. Engineering Record, vol. 74, pp. 575 and 596. (Finds electrolytic treatment of sewage little better than treatment with lime alone.)

13. The Electro-Chemical Sewage Treatment Process as Operated at Decatur, Ill.: Municipal Engineer, February, 1918.
14. Sewage Treatment at Easton, Pa.—Details and methods of operation of plant of 1,000,000 gallons capacity by "direct-oxidation type": Municipal Journal, November 16, 1918.
15. Abstracts of reports by the Pennsylvania State department of health and a committee from the Franklin Institute on tests of the direct-oxidation (electrolytic) plant at Easton, Pa.: Engineering News-Record, September 18, 1919, pp. 569–573.
16. Report of committee appointed to investigate the direct-oxidation method of sewage disposal as demonstrated at the Easton (Pa.) plant (not the exact title): Journal of the Franklin Institute, August, 1919.

GENERAL REFERENCE.

17. Sewage Disposal. George W. Fuller. Pp. 550–576.
18. American Sewerage Practice, Vol. III, Sewage Disposal, p. 738. Metcalf and Eddy.

CONCLUSIONS.

In the preceding chapters relating to current practice of sewage disposal in this country, an attempt has been made to give the essential features concerning each process used in designing purification plants. The particular combination of these processes to be used by an individual city will depend upon local conditions. It is quite apparent that a city, even though it be very large, located on a large river or other large body of water, would not find it necessary to purify its sewage to the same extent that a smaller city would, located on a small stream. In some places the body of water receiving sewage has sufficient diluting capacity to digest the organic matter without causing a nuisance, while in other cases fine screens will be required to remove from the sewage, material which floats and causes objectionable drifts. At the other extreme there are a large number of cities located on small rivers where the minimum flow in summer time is very low, and it is necessary to design treatment plants producing effluents which are thoroughly oxidized and will not draw upon the oxygen of the receiving body of water.

Current practice, therefore, includes one of the processes or any combination of them, described under the various chapter headings, depending upon the local conditions governing at each city. To obtain a comprehensive understanding of sewage disposal in this country, it is suggested that the engineering magazines, reports, and books on sewage disposal referred to in this report, and not inclosed, be secured. Practically all of them can be obtained by writing to the authors or publishers.

The more recent books published on sewage disposal have been referred to by title and author and the name of the publication given. The titles of some of the magazines interested in sewage disposal have, however, been changed in recent years, and some of them may

be confusing as they have appeared in the references. The correct titles and the publishers are given below.

The *Engineering Record* and the *Engineering News* were formerly separate journals, but they have been combined and are now published under the name of the *Engineering News-Record* by the McGraw-Hill Publishing Co., of New York City.

The *Municipal Journal* is now the *Municipal Journal and Public Works* and is published by the *Municipal Journal and Engineer*, at New York City.

Articles appearing in *Engineering and Contracting* are published in the "Waterworks and Hydraulics" issues, which are printed twice each month. This journal is published at 608 South Dearborn Street, Chicago, Ill.

APPENDIX.

A PARTIAL LIST OF PUBLISHED REPORTS ON SEWAGE DISPOSAL IN THE UNITED STATES.

1. Reports relating to sewage disposal for New York City and Brooklyn:
   - (*a*) Report of Metropolitan Sewerage Commission of New York City, August 30, 1914.
   - (*b*) Report on the Main Drainage and Sewage Disposal of the Area Tributary to Jamaica Bay, April 23, 1917.
   - (*c*) Report of Engineers on the Electro-Chemico Corporation Process of Sewage Purification as Operated at the Elmhurst Disposal Plant.
   - (*d*) Article on Sewage and Dissolved Oxygen in New York Harbor, by Kenneth Allen, Engineering News-Record, July 31, 1919.
2. Reports relating to sewage disposal for the Sanitary District of Chicago:
   - (*a*) Report of streams examination, chemic and biologic, of the waters between Lake Michigan at Chicago and the Mississippi River at St. Louis. Sanitary status of Drainage Canal in 1902.
   - (*b*) Report on the Disposal of Sewage from the Calumet Subdivision of the Sanitary District of Chicago. 1907.
   - (*c*) Engineering Data, the Sanitary District of Chicago. 1910.
   - (*d*) Report on Sewage Disposal. 1911.
   - (*e*) Sewerage System of Chicago, also Review of Sewage Disposal in the United States and Abroad. 1911.
   - (*f*) The Diversion of the Waters of the Great Lakes by Way of the Sanitary and Ship Canal of Chicago. 1913.
   - (*g*) Water Power Development—Report by Commission on Sewage Disposal and Water Power Development.
   - (*h*) Report on Pollution of Des Plaines River and Remedies Therefor by the Sanitary District of Chicago. 1914.
   - (*i*) The Electric Department of the Sanitary District of Chicago. Power Developed from Drainage Canal. 1916.
   - (*j*) The Laws of and in Reference to the Sanitary District of Chicago, with Annotations. 1916.
   - (*k*) Report of Existing Lake Levels of Lake Michigan. 1917.
   - (*l*) Experimental Engineering; Particular Reference to the Construction of Testing Stations on Water and Sewage Problems. 1917.
   - (*m*) The Activated Sludge Process for Handling Packingtown Trade Wastes. 1917.
   - (*n*) History and Growth of the Sanitary District of Chicago. 1919.

(o) Memorial: Data on the Drainage Canal.
(p) Maps Showing Territory Sewered by the Sanitary District of Chicago.
(q) Miscellaneous reports on sewage disposal by Langdon Pearse, sanitary engineer for the Sanitary District of Chicago.

3. Reports relating to sewage disposal for Cleveland, Ohio:
   (a) Report on Tests at Sewage Testing Station. 1914.
   (b) Reprint from Engineering News on results of activated sludge treatment. 1916.
4. Reports relating to sewage disposal at Providence, R. I.:
   (a) Annual Report of City Engineer, 1918.
   (b) Plans and Photographs of Disposal Plant (with a description of the plant attached).
5. Brief Description of Sewage Disposal Plants at Atlanta, Ga. 1919.
6. Report of Sewage Testing Station at Akron, Ohio. 1912.
7. Report of Passaic Valley Sewerage Commission, 1916.
8. Report on Sewage Disposal and the Sewage Experiment Station, Gloversville, N. Y. 1908.
9. Report on Sewage Disposal System of Rochester, N. Y. 1913.
10. Reports relating to sewage disposal at Columbus, Ohio:
   (a) Annual Report, 1913.
   (b) Annual Report, 1914.
   (c) Annual Report, 1915.
   (d) Annual Report, 1916.
   (e) Annual Report, 1917.
   (f) Annual Report, 1918.
11. Reports relating to sewage disposal at Milwaukee, Wis.

RURAL PLUMBING.[1]

By GEO. C. WHIPPLE, Professor of Sanitary Engineering in Harvard University, Cambridge, Mass.

The nation-wide movement in favor of better rural living conditions offers opportunities for important extensions of the plumbing business. The movement is found in different stages in different parts of the country, but everywhere it is a progressive movement.

Sanitation is one of its important elements. There are large areas, chiefly in the South, where privies are being constructed for the first time; there are districts where open, surface privies are being replaced by indoor chemical closets, and there are places where indoor water-closets are being installed. The sale of concrete tanks is increasing rapidly, a single factory in a southern city shipping over 2,000 annually.

In its first stages this movement for better sanitation is primarily in the interest of health; in its later stages it is in the interest of both health and comfort.

Plumbers are not interesting themselves as they should in the privy problem, perhaps for the reason that there is no piping and few fixtures to be installed, and they do not see that it has a fundamental relation to their business. Plumbers are naturally called

[1] This article originally appeared in The Plumbers' Trade Journal, Steam and Hot Water Fitters' Review, New York, issue of Oct. 25, 1919, and is reprinted here by permission.